

## A STUDY ON THE ENHANCEMENT OF THERMAL CONDUCTIVITY OF THE HYBRID FILLED POLYMER COMPOSITE HEAT EXCHANGER USING CFD ANALYSIS

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### ABSTRACT

*In the present study, we tried to increase the thermal conductivity of polymer composite material due to the growing need to develop new materials for heat transfer applications. Polymer composite materials have been given enormous importance by many researchers in the field of heat transfer applications due to several advantages that are incorporated with this kind of materials. Since polymers have typical advantages like low cost, corrosive resistance, light weight, higher strengths, good manufacturability. The board utilization of seawater as a coolant can be made conceivable by the positive characteristics of thermally-improved polymer composites. Polymer composites can conquer any hindrance between unfilled polymers and consumption safe metals and can be connected to an assortment of heat exchanger applications. The performance of the double tube heat exchanger is analyzed with the newly manufactured polymer composite. This dissertation shows a structured technique that coordinates thermo-liquid contemplations and assembling issues into a solitary plan instrument for thermally improved polymer heat exchangers.*

**KEYWORDS:** Hybrid Fillers, Thermal Conductivity, Polymers & Double Tube Heat Exchanger

**Received:** Jun 25, 2019; **Accepted:** Jul 15, 2019; **Published:** Sep 18, 2019; **Paper Id.:** IJMPERDOCT201941

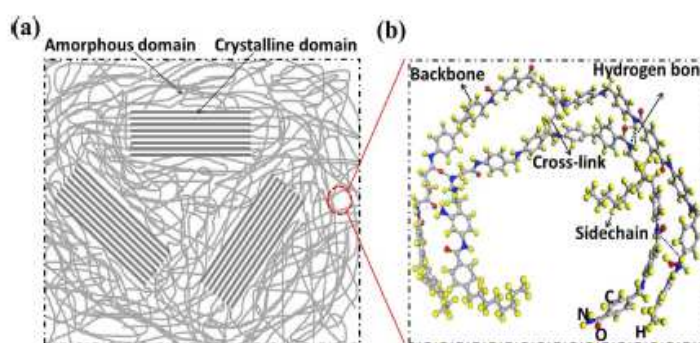
### INTRODUCTION

As the requests in cheaper and light weight corrosion resistant materials are intensifying for the faster heat dispersal in industries these polymer heat exchangers becoming increasingly prominent. Without a doubt, the powerlessness to enough lead heat far from the living environment has forced another designing imperative in numerous new item structures [1]. Under this condition, polymers loaded up with thermally conductive fillers are developing as a financially savvy approach to the new way of manufacturing heat exchangers [2]. Heat transfer improvement in a heat exchanger is getting modern significance since it offers the chance to diminish the transfer area region for the heat exchanger. Increment in the heat exchanger execution can make vitality, material, and cost sparing. Concentric pipe heat exchangers are the easiest gadgets wherein heat is moved from the hot liquid to the chilly liquid through an isolating barrel shaped divider. The principle polymer heat exchanger was first displayed by DuPont [3]. Various undertakings have been made for propelling the business utilization of this kind of heat exchangers. The customary heat exchanger created with metals, (for example, solidified steel, copper and aluminum) has the injuries in the

parts of weight and cost [4]. In extension, phenomenally treated metal heat exchangers are required if the working fluids are ruinous. Given these examinations, it is alluring to find an elective material for heat exchangers that can conquer these preventions and further increasingly secure identical heat exchange capability and be adequately fabricated. This is the spot, where usage of this heat exchanger turns out to be conceivably the most significant.

Likewise, an exceptionally high thermal conductivity of 695 W/mK for polymer lattice composite was obtained with a fortress of 56% by volume, of heat treated VGCF by Yu-Mao Chen [5]. At any rate, composite materials have been seen to be truly important for heat dispersal in electronic packaging [6–9]. One of such composites is the metal cross-section fortifying administrators. These composite materials are for all intents and purposes indistinguishable from that (MMC). Ordinary MMCs, including aluminum framework and copper arrange composites, for polymer as fillers to redesign warm conductivity, (CTE) that can be altered by fluctuating the designing of reinforcing administrators, and they show diminished burden when diverged from unadulterated metals as a result of the wire of lower thickness strengthening pros. These composites fuse carbon-fiber-reinforced aluminum or copper, silicon carbide (SiC) atom sustained aluminum, and valuable stone particle braced aluminum [10–12]. The thermal conductivity of mass polymers is typically low, of 0.1–0.5 W/m K which is a direct result of the eccentric morphology of polymer chains [13]. Figure 1(a) shows an ordinary structure of a polymer, which involves crystalline territories where polymer chains are balanced at times, and indistinct spaces where the polymer chains are discretionarily entangled. The thermal conductivity of a polymer depends gigantically on its morphology. K value as high as 104 W/mK has been cultivated for polyethylene (PE) in the wake of stretching out with a draw extent of 400 for nano fibers with an estimation of 50–500 nm and lengths up to numerous millimeters [14–15].

Despite the structure morphology of polymer chains, another essential system to update the warm conductivity of polymers is to blend polymers with uncommonly high conductive fillers. The headway of nanotechnology over the span of the latest two decades not simply gives progressively different high conductivity fillers of different material sorts and topological shapes yet also advances the understanding at the nano scale. figure 2 shows a sketch of a polymer nano composite to speak to the heat transport frameworks. Exactly when the filler center is low, no between filler frameworks could be confined, as showed up in figure 2 (a). The thermal conductivity is essentially managed by the filler-arrange coupling, i.e., interfacial heat obstacle, and the concentration and the geometric conditions of fillers. Right when the filler center is colossal enough, high conductivity fillers may outline thermally conductive frameworks, as showed up in figure 2(b). The real heated vehicle parts and progressing amalgamation tries in the two sorts of nano composites are assessed. In this present setting, we are thinking about the HDPE [high thickness poly ethylene] as a polymer and Aluminum Nitride as a filler to improve the thermal conductivity.



**Figure 1: Schematic of Polymer: (a) The Morphology of a Polymer Comprising of Crystalline and Indistinct Spaces; (b) Polymer Structure.**

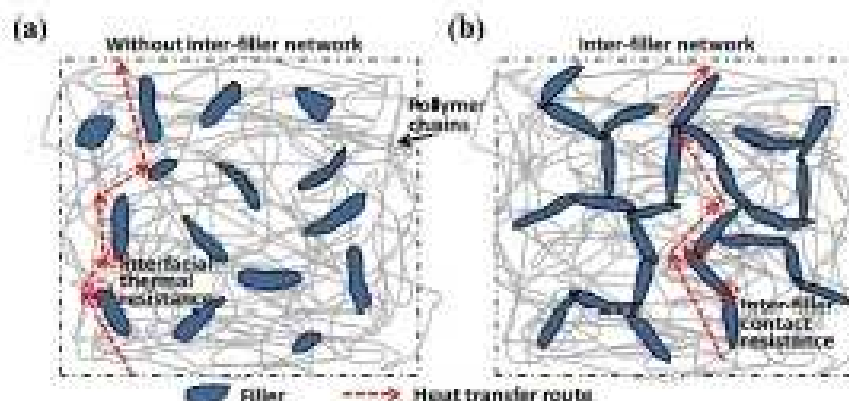


Figure 2: Schematic Charts of Polymer Nano Composites: (a) without between Filler Arrange; (b) with between Filler Systems (Thermally Conductive Pathway is Identified with Dashed Lines.)

## PROPERTIES OF POLYMERS

Table 1: Applications and Working Conditions of Various Available Polymer Heat Exchangers

Type of Heat Exchanger	Dimensions	Working Temperature	Pressure	Applications
Plate	Thickness from 3–6mm	-40°C to 90°C	NA	Ventilation, Humidifying, Electronic cooling etc.
Plate	Plates are made from 0.127 mm film	<148°C	<275 kPa	Corrosive liquid cooling.
Plate	28 x 42 x 7.6 cm	-40°C to 115°C	<550 kPa	Chiller applications
Plate	Walls are less than 0.5 mm	-15°C to 60°C	172 kPa	Can handle airflows with sensible and latent heat exchange
Plate, Coils	NA	NA	NA	Corrosive fluids.

Table 2: Thermal and Mechanical Properties of Different Polymers

Polymer	Density(g/cc)	Thermal Conductivity(W/mK)	Yield Strength(GPa)	Elongation at Break (%)	Melting Point(°C)
LCP	1.82	18–20	45	3.4	212–280
PEA	2.12	0.05	13.8	300	310
PC	1.2	0.2	62	98	340
HDPE	1.78	0.28–037	99	32.4	135
PPS	1.43	0.3	69	4	280
PPSU	1.29	0.35	72	60	NA
PP	0.94	0.11	31	120	160
PS	1.05	0.14	44	6.9	NA
PSU	1.24	0.22	75	56.8	NA
PTFE	2.1	0.27	12	400	330
PVDF	1.78	0.19	44	64.6	160

A polymer is a huge particle, or full-scale atom, made out of many rehashed subunits. Polymers reach out from understood fabricated plastics, for instance, polystyrene to trademark biopolymers, for instance, DNA and proteins that are vital to natural structure and limit [16]. The most normally utilized polymers and their physical properties are accounted for in tables 1 and 2. The information was gathered utilizing both an online database (Matweb, <http://www.matweb.com>) and specialized distributions. The short material portrayals are exhibited taken from specialized papers [16–21]

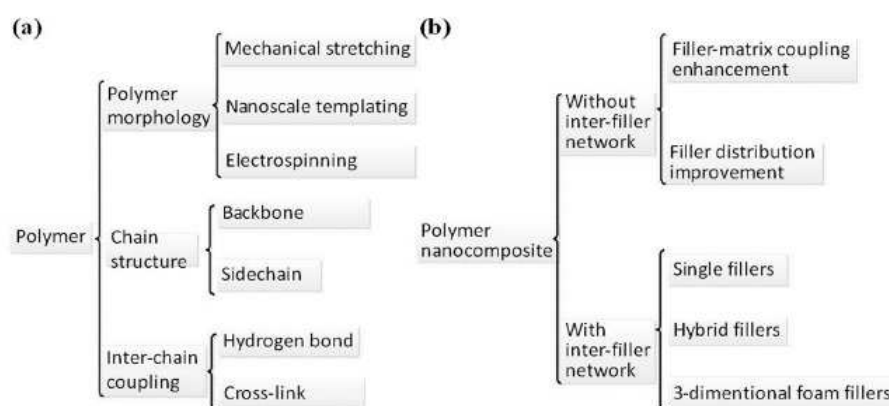
After thoroughly studying the properties HDPE material is selected in the present case due to its low cost and its high density that makes it more suitable for easy mixing.

## METHODS TO ENHANCE THERMAL CONDUCTIVITY

Extending the chain game plan is thus expected to update the  $K$  value of polymers. In crystalline polyethylene (PE) nano strands, the intentional conductivity could be as high as  $104 \text{ W} \cdot \text{m}^{-1} \text{ K}^{-1}$  [22]. There have quite recently been a couple of exploratory techniques that appeared to improve the degree of the chain course of action. For example, the chain game plan could be improved by heat toughening [23–25]. Exploratory examinations on the poly(vinyl-idene fluoride trifluoro ethylene) [P(VDF-TrFE)] polymer showed that when the polymer film was toughened over its dissolving temperature (421 K), a 300–400 % development of  $K$  value occurs because of the chain game plan [26], which has moreover confirmed by various works [27, 28]. In this portion, some test systems which have been successfully associated with improve the chain plan, for instance, the mechanical extending, nano scale templating, electro spinning and presentation of hybrid fillers are dense in Sections 3.1–3.4. [29, 30].

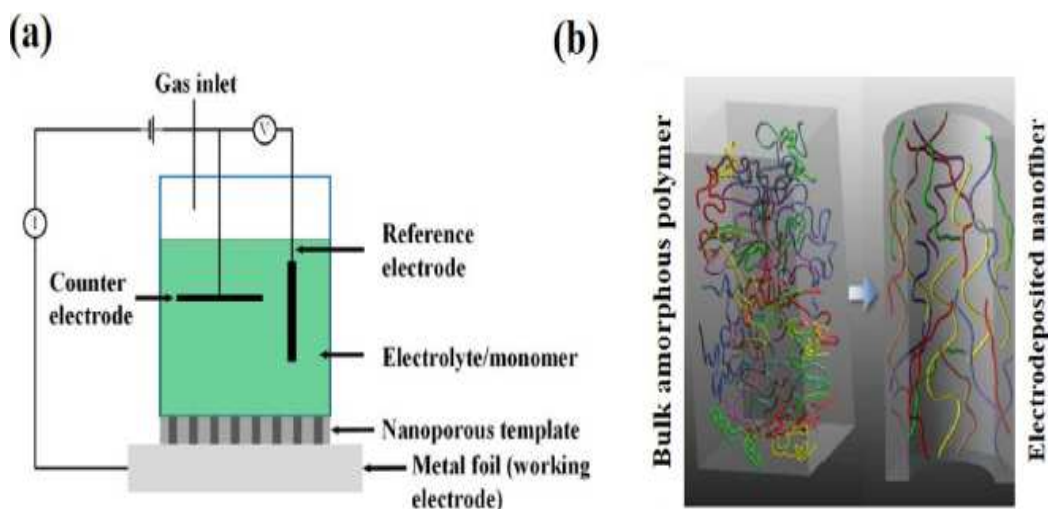
### Mechanical Stretching

Thermal conductivity of polymers can essentially be expanded by Mechanical extending in light of the expanded direction of the chains in a polymer and was shown by Chey et al. [31–33]. In his exploration he found that the  $K$  worth was fundamentally come to  $40 \text{ W/mK}$  and more for the ultra-weight polyethylene (UHMW-PE) after extending the polymer to a draw proportion of 300. Shen et al. [22] utilized two fold stage heating method and accomplished higher draw proportion of 400 was accomplished which joined a high warm conductivity of  $104 \text{ W/mK}$ .



**Figure 3: Physical Systems Influencing the Thermal Conductivity of: (a) Polymers; (b) Polymer Nano Composites.**

### Nano Scale Templeting

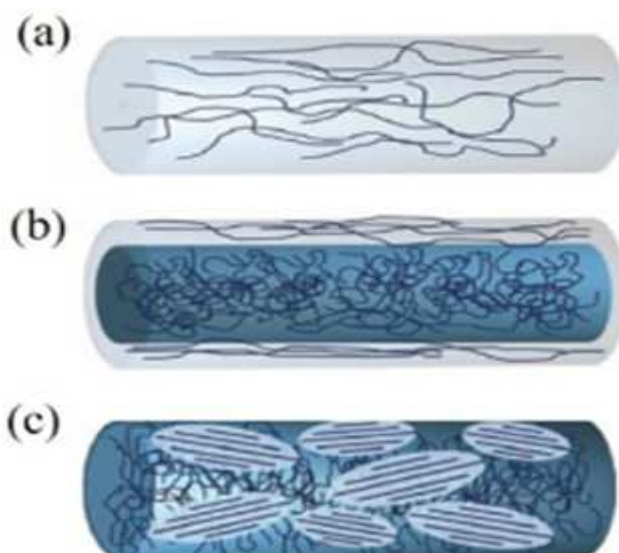


**Figure 4: Nano scale Templeting [15].**

Nano scale templeting is another approach to adjust polymer chains. Polymers are softened and penetrated in a permeable format, for example, permeable anodic alumina. Evacuating the permeable anodic alumina layout utilizing NaOH fluid arrangement left with a variety of polymer nano fibers [34].

### Electro Spinning

Electro spinning is a nano fiber creation strategy which jobs electrostatic forces to draw charged strings of polymeric course of action. A polymer is separated in a synthetic arrangement and held in a store. As shown by the degree of polymer chain game plan in an electro spun fiber, Canetta et al. [36] dense the possible headings of the chains in a polymer as showed up in figure 5.



**Figure 5: Directions of Polymer Chains: (an) a Nano Fiber with Best Balanced Chains; (b) A Middle Shell Morphology with the Shell Formed by Balanced Chains and Focus Included Erratically Masterminded Chains; (c) A Super-Sub-Nuclear Morphology with Balanced Chain.**

### Use of Hybrid Fillers

High thermal conductivities can likewise be acquired by bringing fillers into the polymer lattice. It tends to be done in three different ways for example a) Metallic fillers b) Non-metallic fillers or Ceramic fillers and c) Carbon based nano fillers. Because of the expansion of metallic fillers however, there will be an increment in K esteem yet the electrical conductivity and erosion obstruction will be truly influenced which isn't ideal. With the expansion of non-metallic fillers this issue can without much of a stretch be understood yet K worth will be 10 to 20% will be not as much as that accomplished if there should arise an occurrence of metallic fillers. The referenced drawbacks can be overwhelmed by presenting carbon nano cylinders and carbon nano strands like Vapor developed carbon fiber (VGCF) [5]. The various properties of fillers and grid have appeared in the table 3.

**Table 3: Properties of Fillers and Polymer Matrix**

Materials	Symbol	Density (g/cc)	CTE (ppm/°C)	Particle Diameter (µm)	Particle Length (µm)	Thermal Conductivity (W/mK)
Matrix	HDPE	0.945	198	<150	-	0.45-0.55
	AlN	3.26	4.3	4	-	150-220
Filler	Wollastonite	2.8	5.4	2	40-50	2.5
	SiC	3.2	4.7	0.7-1	Oct-15	85
	BN	2.27	4.3	04-May	-	29

## EXPERIMENTAL WORK

### Preparation of the Composite Sample

In the present experiment, HDPE polymer is mixed with some non-metallic fillers like AlN (Aluminium Nitride), BN (Boron Nitride) and SiC (Silicon Carbide) which are known to have higher thermal conductivities. The shapes of BN is plate shaped, AlN is roughly spherical and that of SiC is whisker.

### Surface Modification of Both Fillers and Matrix

We can use coupling agents like Decalin (organic) up to 110 to 120°C or hot benzene or hot toluene or titanate coupling agent (KR-189, China Ajinomoto for HDPE matrix). In this present case, we used Decalin as a coupling agent which ensures a proper interface between filler and the matrix and also to have good dispersion between them.

### Procedure

The following procedure was followed for the modification of the surfaces of both fillers and matrix

- Mixing the HDPE filler and Decalin in presence of Carbon Tetra Chloride (CCl<sub>4</sub>) around a temperature of 90°C for 150 minutes.
- Vacuum drying is employed to remove the dissolved solvent at 125°C for 36 hours.
- Then the treated materials were to be stored at 90°C to protect them from absorbing water.

### HDPE Composite Sample

Both the matrix (HDPE+AlN) and the fillers (SiC+GRAPHITE) are vacuum dried at 120°C for 4 hours and 100°C for 8



hours respectively. Then by using Twin-Screw extruder the mixing of fillers and HDPE matrix at 200 rpm for 300 minutes. Since we have lower filler content (less than 50%), by using injection molding at 250°C sample was prepared. For composites having higher filler content (60% and above) injection mode is not possible so in contrast we go with compression molding at 200°C for the sample preparation. In the present study a sample of 5 kg was taken consists of 1 kg HDPE + 2 kg AIN +1kg SIC +1 kg graphene. At the end of filler and matrix mixing, 5 gm. of CNT is added to it for improving K value. After the molds were prepared by using injection molding the specimens were tested for the required properties.

### Testing

The following tests were conducted for the specimen:

**Thermal Conductivity (K):** This test was conducted as per ASTM E 1530 standard. The size of the specimen was a circular disc of diameter 50 mm and thickness 5mm. The thermal conductivity of the polymer composite was found to be 89.5W/mK.

**CLTE** (Coefficient of Linear Thermal Expansion- $\alpha$ ): The specifications of the test specimen are 63.5mm×12.7mm×3.8mm. CLTE was found by using ASTM E 696 method and value was read as  $18 \times 10^{-5} / ^\circ\text{C}$ .

**Density ( $\rho$ ):** Using ASTM E D792 and ISO:1183 the density was calculated as 0.989 g/cc

## SIMULATION OF A DOUBLE PIPE HEAT EXCHANGER USING THE ABOVE RESULTS

A double pipe heat exchanger is simulated with the obtained thermal conductivity.

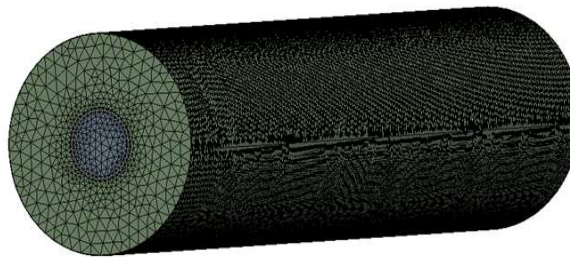
### Geometry and Mesh

The geometry of the double pipe heat exchanger taken for the analysis is mentioned in the below table. The three-dimensional model is then discretized in ICEM CFD, so as to catch both the thermal and velocity boundary layers the whole model is discretized utilizing hexahedral work components which are exact and include less calculation exertion. The governing equations of fluid flow represent mathematical statements of the conservation laws of physics:

- The mass of fluid is conserved.
- The rate of change of momentum equals the sum of the forces on a fluid particle
- **Navier-Stokes Equation:**
- $\partial u + \partial v = 0$
- The rate of change of energy is equal to the sum of the rate of heat addition and the rate of work done on fluid particle
- **i.e.**  $E = \frac{1}{2}(u^2 + v^2 + w^2) + i$
- Where  $i$  = internal energy and  $u, v, w$  are velocity components.
- Navier-Stokes equation as solved in each and every module of the CFD solver.

Table 4: Specifications of the Double Pipe Heat Exchanger	
Specifications	Dimensions(mm)
Total length of the pipe	1500
Outer diameter of the outer pipe	100
Thickness of the outer tube	4
Outer diameter of the inner pipe	30
Thickness of inner pipe	1.5

### Meshing



**Figure 6: Mesh Model of the Concentric Pipe Heat Exchanger.**

At first a decently coarser mesh is made with 1.8 Million cells. This mesh contains mixed cells (Tetra and Hexahedral cells) having both triangular and quadrilateral appearances at the cutoff points. Care is taken to use composed cells (Hexahedral) anyway much as could sensibly be normal; subsequently, the geometry is divided into a couple of areas for using modified methodologies open in the ANSYS fitting client. Later on, for the work free model, a fine work is made with 5.65 Million cells.

### CFD Analysis of Heat Exchangers

Computational Fluid Dynamics investigation is performed on heat exchanger thinking about the above determinations and the material property (K value was taken as 89.7 W/mK). In all the simulations constant water of mass flow rate of 0.2 Kg/s in both hot and cold tube has been assigned. The hot water and cold water temperatures are taken as 293K and 332 K respectively. All 3D models have been generated using solid works 3D modeling software. Inner and outer pipes are modeled separately and assembled in a solid works assembly module. CFD simulation is carried out using Ansys Workbench. Pre and post processing has been carried out in Ansys workbench while solving is done in Fluent Solver of Ansys. Both parallel and counter flow conditions have been analyzed.

For the simulated models, heat exchanger in counter flow has got a higher heat transfer value when compared to that of parallel flow. The temperature profiles of both parallel and counter flow are shown in the figure 7& figure 8 below.

The detailed results of hot water inlet and outlet and cold water inlet and outlet temperatures have been represented in the table 5



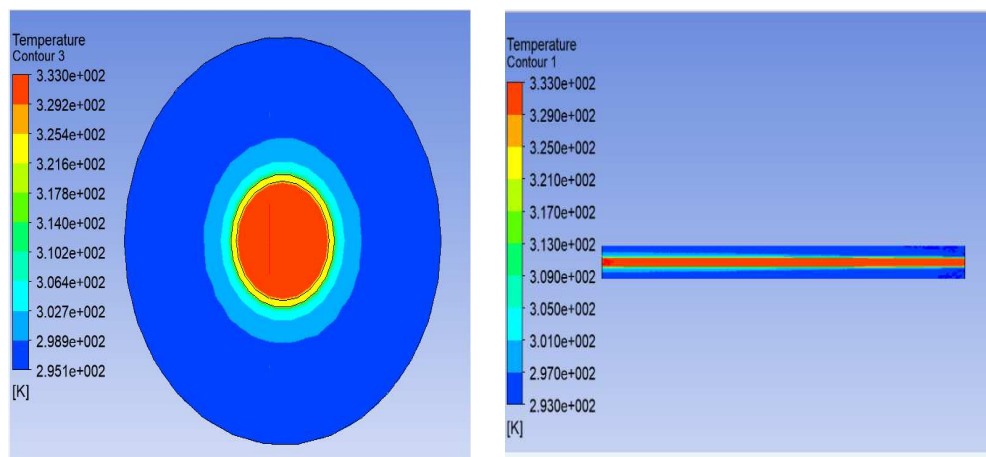


Figure 7: Temperature Profiles of Counter Flow Type.

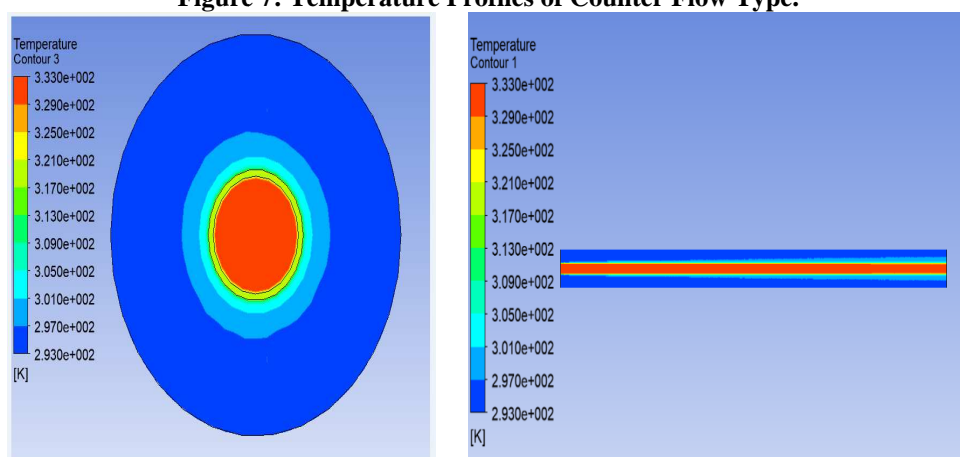


Figure 8: Temperature Profiles of Parallel Flow Type.

Table 5: Results of Temperature Distribution

S. No.	Material	Flow	Domain	Inlet Avg. Temperature (K)	Outlet Avg. Temperature(K)
1	HDPE	Parallel	Cold fluid	293.0246	299.9494
2	HDPE	Parallel	Hot fluid	332.9812	326.0757
3	HDPE	Counter	Cold fluid	293.0246	300.9187
4	HDPE	Counter	Hot fluid	332.9812	325.1819

### Calculation of the Effectiveness

The ratio of actual heat transfer to the maximum possible heat transfer for any heat exchanger

$$\epsilon = \frac{T_{co}-T_{ci}}{T_{hi}-T_{ci}} [\text{Because } m_c = m_h = 0.2 \text{ kg/sec}]$$

Where

$T_{ci}$ ,  $T_{co}$  = Temperature of the cold water at the inlet and outlet respectively.

$T_{hi}$ ,  $T_{ho}$  = Temperature of the hot water at the inlet and outlet respectively.

Table 6

Effectiveness (Parallel Flow)	Effectiveness (Counter Flow)
$\varepsilon=0.1538$	$\varepsilon=0.1798$

## CONCLUSIONS

In this work, the various methods for enhancement of K value for polymers have been explained in detail. After testing the obtained K value of the HDPE polymer composite CFD simulation was done in both parallel and counter flow conditions. The effectiveness  $\varepsilon$  for counter flow was greater than that of parallel flow. Though the K value was lower when compared to that of commonly used metals but with the above explained thermal conductivity enhancement techniques it may be further increased, which could be a worthwhile consideration in the field of thermal engineering. The incorporation of mechanical stretching and the use of hybrid fillers to the stretched polymer may have a significant impact on the K value.

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